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RESEARCH MEMORANDUM

A PRELIMINARY INVESTIGATION AT MACH NUMBER 1.91 OF A DIFFUSER EMPLOYING A PIVOTED CONE TO IMPROVE OPERATION AT ANGLE OF ATTACK

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

A PRELIMINARY INVESTIGATION AT MACH NUMBER 1.91 OF A DIFFUSER EMPLOYING A PIVOTED CONE TO IMPROVE OPERATION AT ANGLE OF ATTACK

By Milton A. Beheim

SUMMARY

A preliminary investigation was conducted to determine the performance of a conical-nose supersonic diffuser at angle of attack. The inlet employed a pivoting cone which could be orientated at any of several angles relative to the free-stream direction independent of the angle of attack of the diffuser. The investigation was conducted at a Mach number of 1.91 over an angle of attack range from 0° to 14°. At all angles of attack of the diffuser the stable subcritical mass-flow ranges and peak pressure recoveries obtained with a fixed-cone inlet could be exceeded by alining the cone closely with the free-stream direction. Performances at critical operation were not appreciably altered by alining the cone in this manner.

INTRODUCTION

Numerous investigations have shown that the performance of conventional conical diffusers deteriorates with increasing angle of attack (e.g., ref. 1). Several studies have been conducted of inlet configurations designed to be less sensitive in this respect. In reference 2 are found the results of such an investigation of a vertical-wedge inlet. Similarly, reference 3 reports the results of an investigation of a half-cone inlet with a flat plate as the upper surface. Both investigations succeeded in achieving somewhat improved angle of attack operation.

The present investigation is a continuation of these studies. This inlet is similar to the conventional conical diffuser with the exception that the conical portion of the centerbody may be pivoted to any of several angles relative to the free-stream direction regardless of the angle of attack of the diffuser. Alining the cone with the free stream as the angle of attack of the inlet was varied would make it possible to maintain a symmetrical flow field ahead of the inlet throat. As a result, difficulties associated with local flow angularities and with separation

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and lack of compression on the lee side of conventional fixed cones could be largely avoided. The investigation was conducted at the NACA Lewis laboratory at a Mach number of 1.91 over an angle of attack range from 0° to 14°.

SYMBOLS

The following symbols are used in this report:

A flow area 3099

m mass flow

P total pressure

R inlet radius

x lineal distance

α angle of attack

θ geometric angle

Subscripts:

l angle between line joining undeflected cone tip with cowl lip and axis of model

s angle between conical shock and axis of cone

t station at throat of diffuser

0 station in free stream

1 station at exit of subsonic diffuser

APPARATUS

The investigation was conducted in the Lewis 18- by 18-inch wind tunnel at a Mach number of 1.91 and a Reynolds number based on cowl lip diameter of 7.1×10^5. The tunnel total temperature was 150° F, and the dew point varied from 0° to -27° F.

Photographs of the model appear in figure 1 for the conditions of no deflection and maximum deflection of the cone. The desired positions of the cone were obtained, as indicated in figure 2, by affixing the

cone in the centerbody to replaceable wedges machined to the desired angle. To avoid internal contraction as the cone was pivoted, the center of rotation was determined by the intersection of the diffuser axis with a line drawn normal to the cone surface and through the cowl lip. Fore and aft positioning of the cowl lip was accomplished with cowl spacers shown in figure 2. A 25° half-angle cone was selected to obtain the optimum theoretical pressure recovery. The subsonic diffuser was designed with the initially slow rate of divergence of about $1\frac{1}{2}$ percent per hydraulic diameter, based on the cross section at the lip, for a length of 3.1 hydraulic diameters. The flow area distributions for two cowl lip positions are also given in figure 2.

Diffuser angle of attack was established with the support mechanism, and diffuser mass flow was varied by the positioning of a sonic exit plug. Diffuser total-pressure measurements were made with a 41 pitot tube rake located at the exit of the subsonic diffuser and were recorded on a tetrabromoethane manometer board. Mass flow was computed using the average total pressure and the area contraction from the combustion chamber to the choked exit.

RESULTS AND DISCUSSION

The total-pressure recovery and mass-flow characteristics of the diffuser at zero angle of attack with differing cowl lip positions are shown in figure 3. When the cowl lip was positioned upstream of the conical shock wave, the stable subcritical mass-flow range was about 80 percent and critical pressure recovery was also the peak. Since the vortex sheet did not intersect the cowl lip with these cowl positions, subcritical stability was expected in accordance with the results in reference 4. The stability was unusually large, however, and may have been a result of the stabilizing effect of the long throat designed from data presented in reference 5. After buzz had started, it was necessary to increase the mass-flow ratio by about 30 percent to regain stability. Increasing the combustion-chamber volume by about 300 percent by discharging through a long pipe had no effect on stability with $\theta_l = 45.8^\circ$. The performance with $\theta_l = 44.2^\circ$ (a cowl position at which the conical shock of 44.0° was very near the lip) was somewhat erratic in that to obtain the low nonbuzzing mass flows, the flow through the diffuser had to be reduced fairly rapidly with only very short pauses to obtain data. If not, buzz resulted at higher mass-flow ratios than indicated. This phenomenon did not occur at the other cowl lip positions.

When the cowl lip was located downstream of the conical shock wave, the stability of the diffuser was very sharply reduced to only about 8 percent and peak pressure recovery occurred at subcritical mass flows.

The shadowgraphs in figure 4 show that with these cowl lip positions the vortex sheet did cross the lip. However, the mass-flow ratios at which buzz was impending were not in all cases those at which the vortex sheet had just entered the cowling. The positions of the terminal shock relative to the cowl lip at minimum stable mass flow were comparable, indicating the possibility of buzz being triggered by shock-induced separation on the centerbody. If such were the case, however, it is not clear why positioning the cowl lip upstream of the conical shock improved the stability. The present theories on buzz do not seem to explain the situation adequately. 3089

Because the diffuser performance was so affected by cowl lip position, the effect of pivoting the cone at angles of attack of the diffuser was investigated with cowl lip positions of 41.8° and 44.7° providing performances representative of the types obtainable. In figure 5(a) are shown the pressure recovery and mass-flow characteristics of the diffuser utilizing a cowl lip position angle of 41.8° at several angles of attack without pivoting the cone. The subcritical stability steadily decreased with increasing angle of attack from its initially small value at zero angle of attack. Peak pressure recovery decreased by 13 percentage points as the angle of attack increased from 0° to 14°, and the decrease in critical pressure recovery was about 14 percentage points. The supercritical mass-flow ratio also decreased by about 9 percent. Figure 5(b) gives the diffuser characteristics at the same angles of attack and cowl lip position but with the cone pivoted to approximately aline with the free stream. A negative sign has been assigned to the deflection angle of the cone because its sense of rotation is opposite to that of the angle of attack. Pivoting the cone in this manner resulted in very little change, relative to the unpivoted condition, in the supercritical and critical operation of the inlet at all angles of attack; but the subcritical performance was considerably altered. In particular, subcritical stability increased as the angle of attack increased. At 14° angle of attack this range was about twice as large as it was at 0°. Furthermore, the loss in peak pressure recovery with angle of attack was only half as great with the cone so pivoted; but this higher pressure recovery occurred at relatively low mass-flow ratios.

The improvement in angle of attack performance by alining the cone with the free stream was even more pronounced with the cowl lip position angle of 44.7°. If the cone was not pivoted, as demonstrated in figure 5(c), the subcritical stability, which was unusually large at zero angle of attack, was very sensitive to angle of attack. With an increase in angle of attack to 3° (the smallest increment investigated from zero angle of attack) or more, this stable range was sharply reduced to only about 6 percent. At some angles of attack stability was regained at mass-flow ratios too low to be of practical interest. The losses in peak pressure recovery and supercritical mass flow relative to the zero angle of attack values as the angle of attack

increased to 14° were very similar to those discussed previously with $\theta_l = 41.7°$. Critical pressure recovery, however, was reduced by as much as 18 percentage points. With the cone again pivoted to aline with the free stream for this new cowl position (fig. 5(d)) very large ranges of subcritical stability were maintained over the angle of attack range. Even at 14° angle of attack this range was as large as 34 percent. As with the previously discussed cowl lip position, the loss in peak pressure recovery was only half as great when the cone was alined with the free stream; but again this peak occurred at very low mass-flow ratios. Critical performances again remained approximately unchanged. Because these large losses in total-pressure recovery still existed near critical operation at angle of attack, methods to improve internal flow may still be needed. Negligible effects were observed at both cowl positions with roughness on the cone tip and with the small gap between the cone and centerbody filled to provide a smoother surface.

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In figure 6 the pressure recovery and mass-flow characteristics of the diffuser are presented at various angles of attack for each of several deflections of the cone with a cowl lip position angle of 44.7° at 0° cone deflection. These data indicate that pivoting the cone toward the direction of the free stream generally improved the peak pressure recovery and subcritical stability at all angles of attack; but to derive the most improvement, the cone must be alined closely with the free stream. The smallest increment in cone deflection of 2° from the free-stream direction used in this investigation was too large to maintain the large stable range of mass flow. Because of this sensitivity, a continually variable deflection cone would probably be required in practical applications.

The shadowgraph and schlieren photographs presented in figures 7 and 8 clearly show the improvement in external air flow during subcritical operation at angle of attack by orientating the cone with the free stream. Figure 7 indicates that when the cone is not pivoted, severe separation occurs on the lee side of the cone well upstream of the terminal shock at minimum stable mass flow. Thus, at relatively high subcritical mass-flow ratios, centerbody separation seemingly became so acute that buzz was instigated. In figure 8, with the cone alined with the free stream, much lower mass-flow ratios were obtained before a separation completely around the centerbody, downstream of the terminal shock, became severe. Thus large subcritical stabilities were obtained at high angles of attack by reducing centerbody separation.

Figure 9 presents Mach number contour maps following diffusion for a variety of operating conditions. Figures 9(a) and (b) show that at zero angle of attack there is a somewhat smaller velocity variation with a cowl lip position behind the conical shock than ahead of it. They also indicate that a reasonable profile was obtained during critical operation at zero angle of attack. Figure 9(c) shows that even at

relatively low angles of attack, the velocity profile can become quite poor at critical operation. At angle of attack, cowl lip position had little effect on these profiles for comparable operating conditions. As the angle of attack increased to 10° (fig. 9(d)) and greater, these profiles were even more unsatisfactory. The very low velocity region indicated that flow separation may have occurred upstream, probably near the cowl lip on the portion of the cowling inner surface where a large turn was required because of the angle of attack. A comparison of figures 9(d) and 9(e) indicates that the pivoting of the cone into the free stream had little effect on the velocity profile at comparable operating conditions. During the investigation, while operating at angle of attack very near and at the critical pressure recovery (i.e., with the terminal shock in the vicinity of the throat), observed velocity profiles indicated considerably more separation than during supercritical or subcritical operation. Figures 9(d), 9(f), and 9(g) illustrate this change. At rather high angles of attack, while approaching critical operation by moving the normal shock upstream toward the throat, these indications of separation occurred abruptly in many instances. For this reason, scatter of data (in particular, reduced mass flows) was noticeable at critical pressure recovery at angle of attack in figures 5 and 6. Schlieren observation, however, indicated no such change in mass flow. This scatter may then have been due to inaccuracy in the method of calculation of mass flow under such separated flow conditions.

SUMMARY OF RESULTS

A preliminary investigation at Mach number 1.91 to angles of attack of 14° of the air-handling characteristics of an axially symmetric nose inlet employing a pivoted conical compression surface yielded the following results:

1. With the inlet at angle of attack, alining the conical compression surface closely with the free-stream direction markedly increased the buzz-free subcritical mass-flow range of the diffuser compared to that with a fixed cone.

2. The loss in peak pressure recovery with angle of attack was only half as large if the cone was alined with the free stream. These higher pressure recoveries occurred, however, at relatively low mass-flow ratios. The critical performance and the velocity profiles of the diffuser were not improved at angle of attack by alinement of the cone with the free stream.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, October 9, 1953

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2. Leissler, L. Abbott, and Hearth, Donald P.: Preliminary Investigation of Effect of Angle of Attack on Pressure Recovery and Stability Characteristics for a Vertical-Wedge-Nose Inlet at Mach Number of 1.90. NACA RM E52E14, 1952.

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4. Ferri, Antonio, and Nucci, Louis M.: The Origin of Aerodynamic Instability of Supersonic Inlets at Subcritical Conditions. NACA RM L50K30, 1951.

5. Nettles, J. C.: The Effect of Initial Rate of Subsonic Diffusion on the Stable Subcritical Mass-Flow Range of a Conical Shock Diffuser. NACA RM E53E26, 1953.

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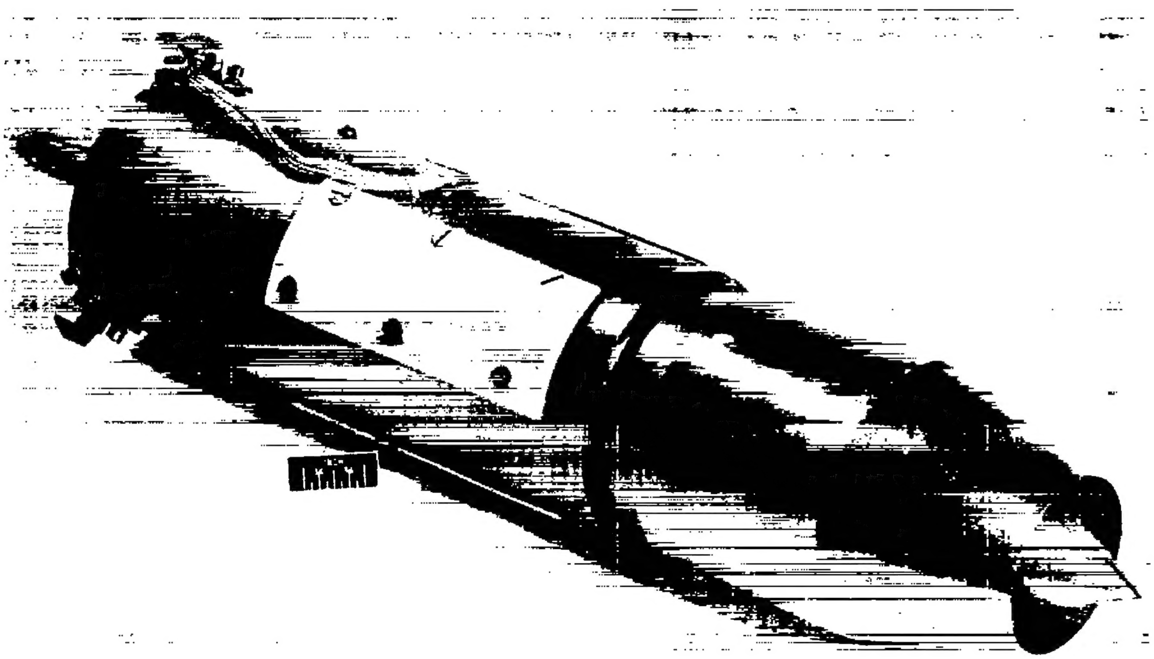

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(a) Assembled diffuser; cone deflection, 0°.

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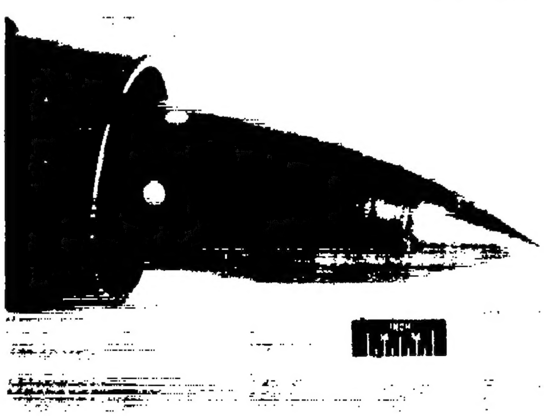

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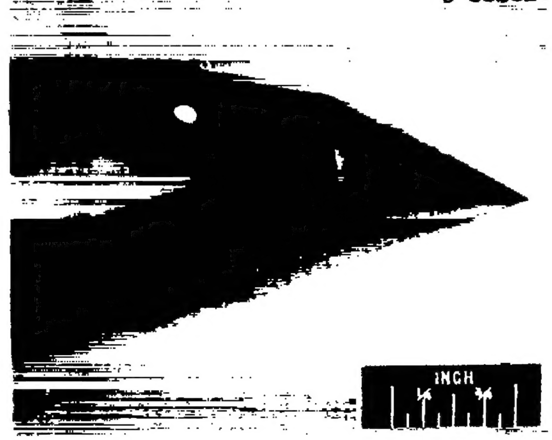

(b) Cowl removed; cone deflection, 0°.

(c) Centerbody; cone deflection, 14°.

Figure 1. - Photographs of model configuration.

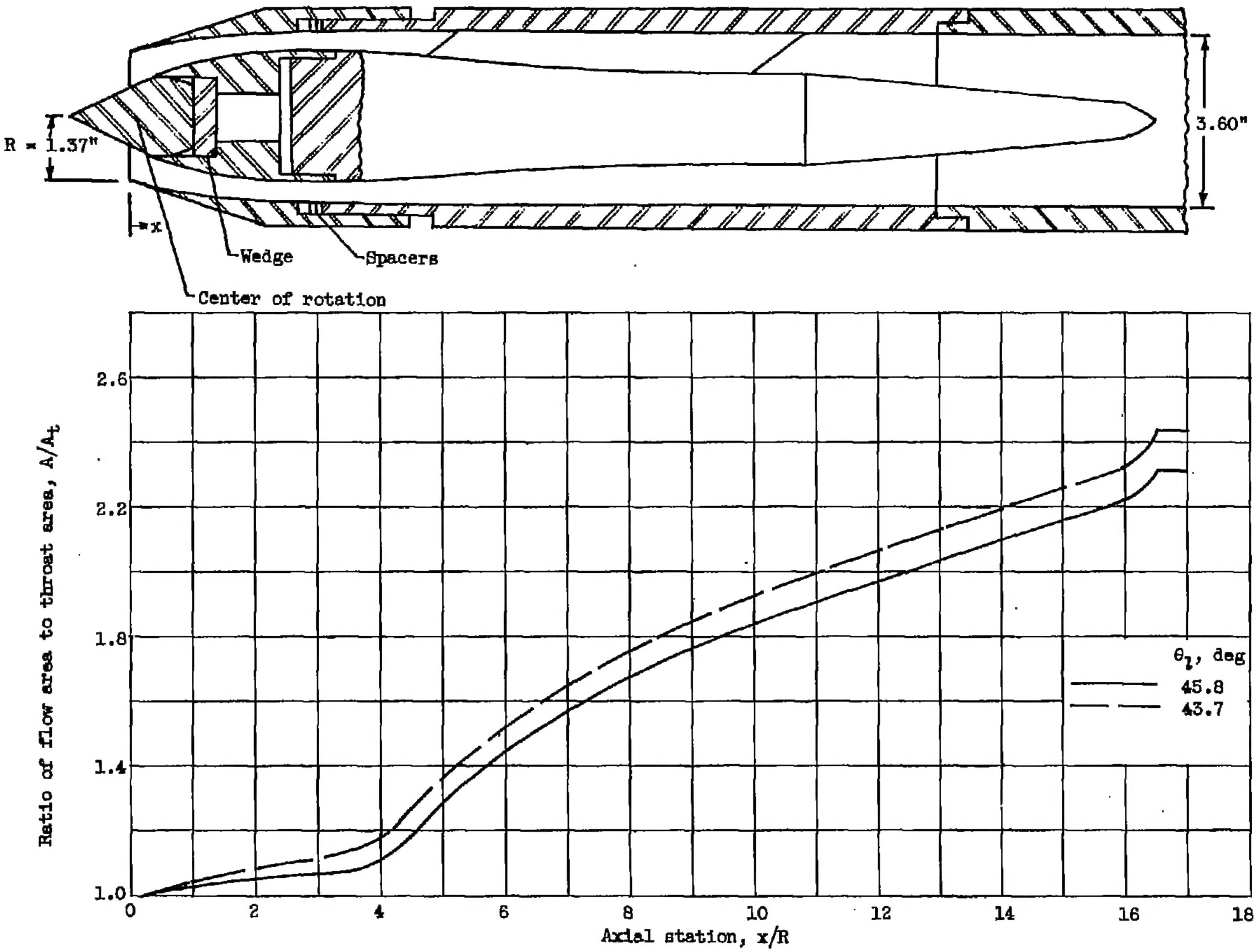

Figure 2. - Sketch of model and distribution of diffuser flow area.

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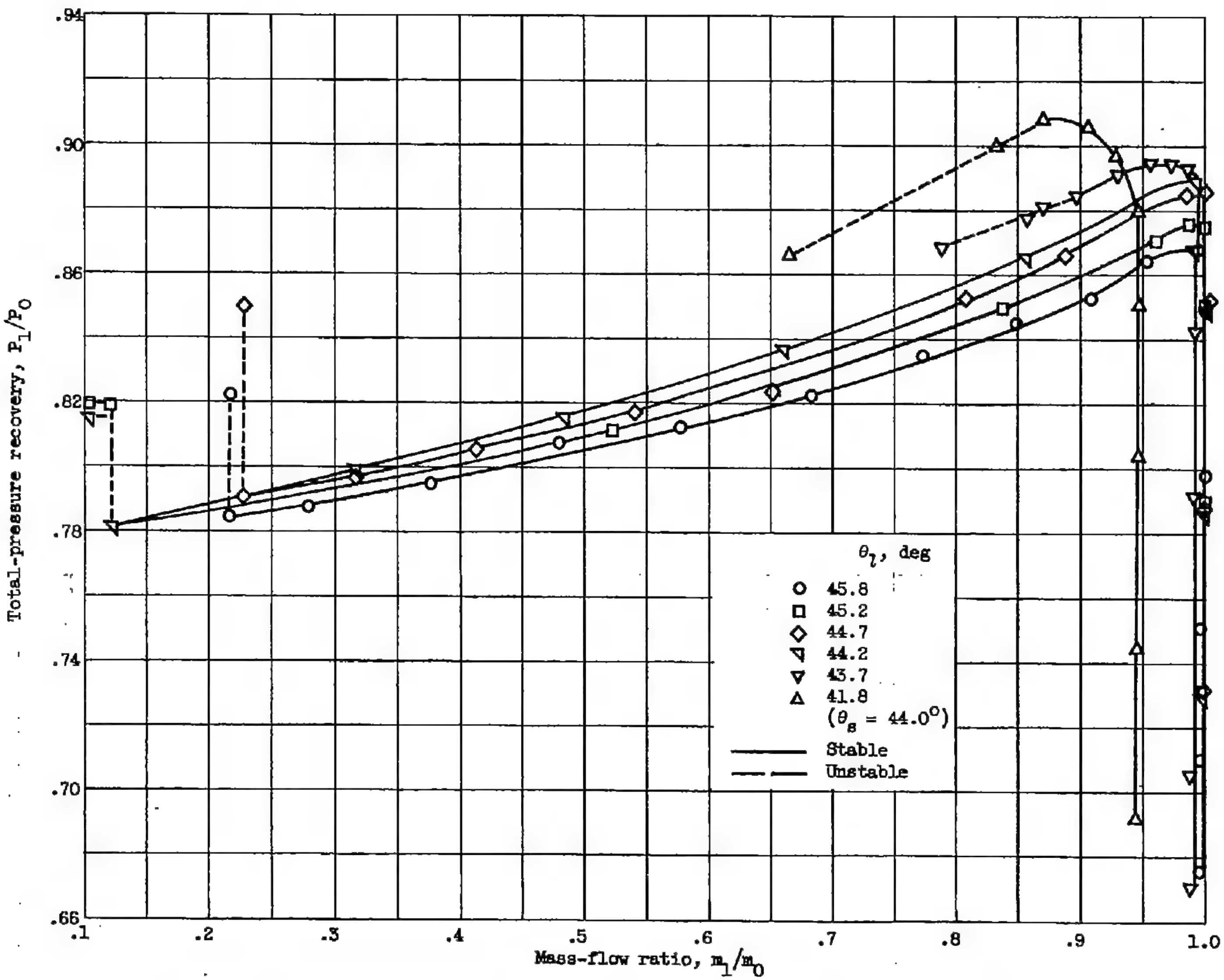

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Figure 3. - Effect of cowl lip position on diffuser performance at zero angle of attack.

$\theta_l = 41.8^\circ$ $\theta_l = 43.7^\circ$ $\theta_l = 44.7^\circ$

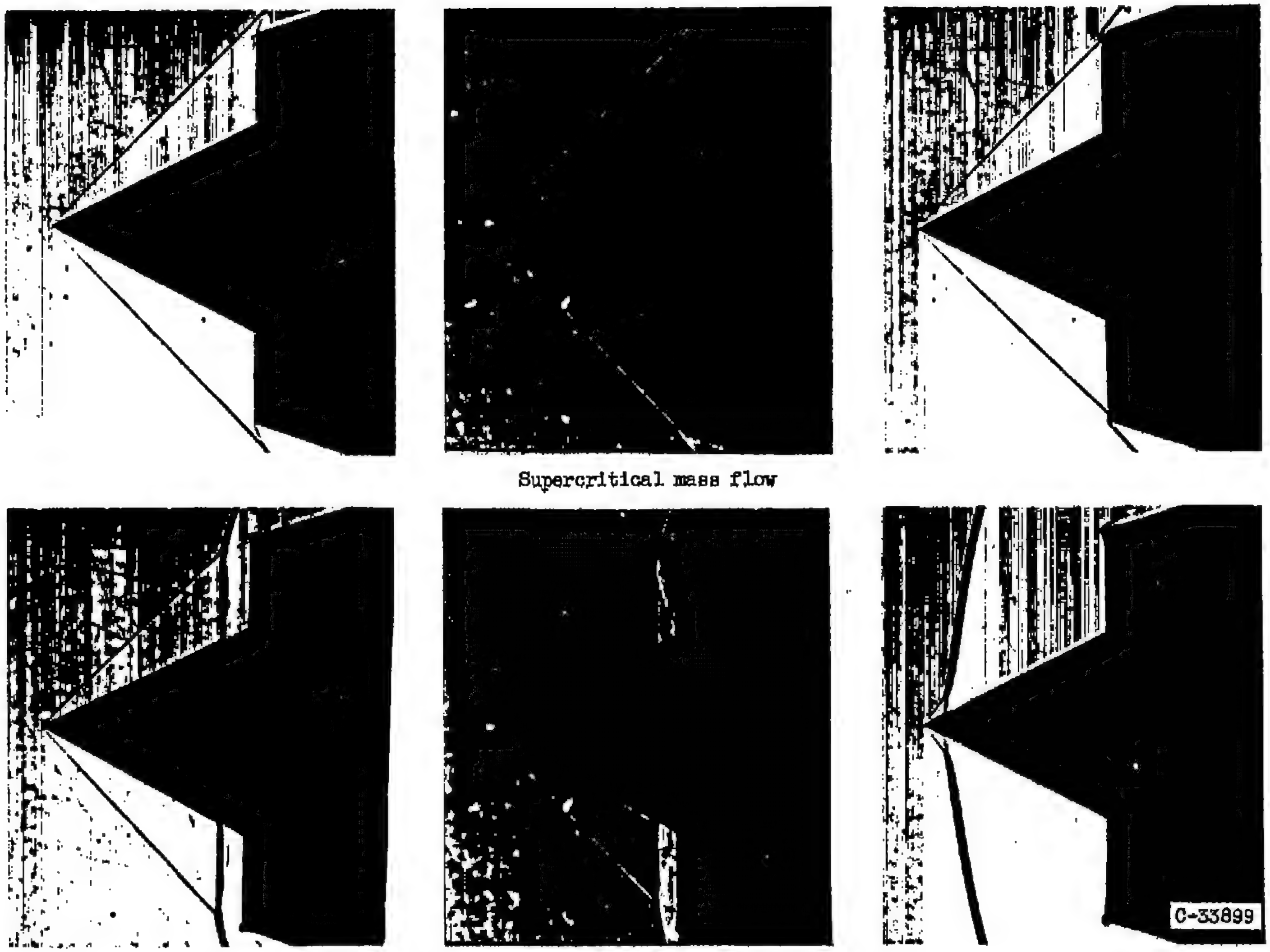

Figure 4. - Shadowgraphs of inlet at zero angle of attack for different cowl lip positions and inlet mass flows.

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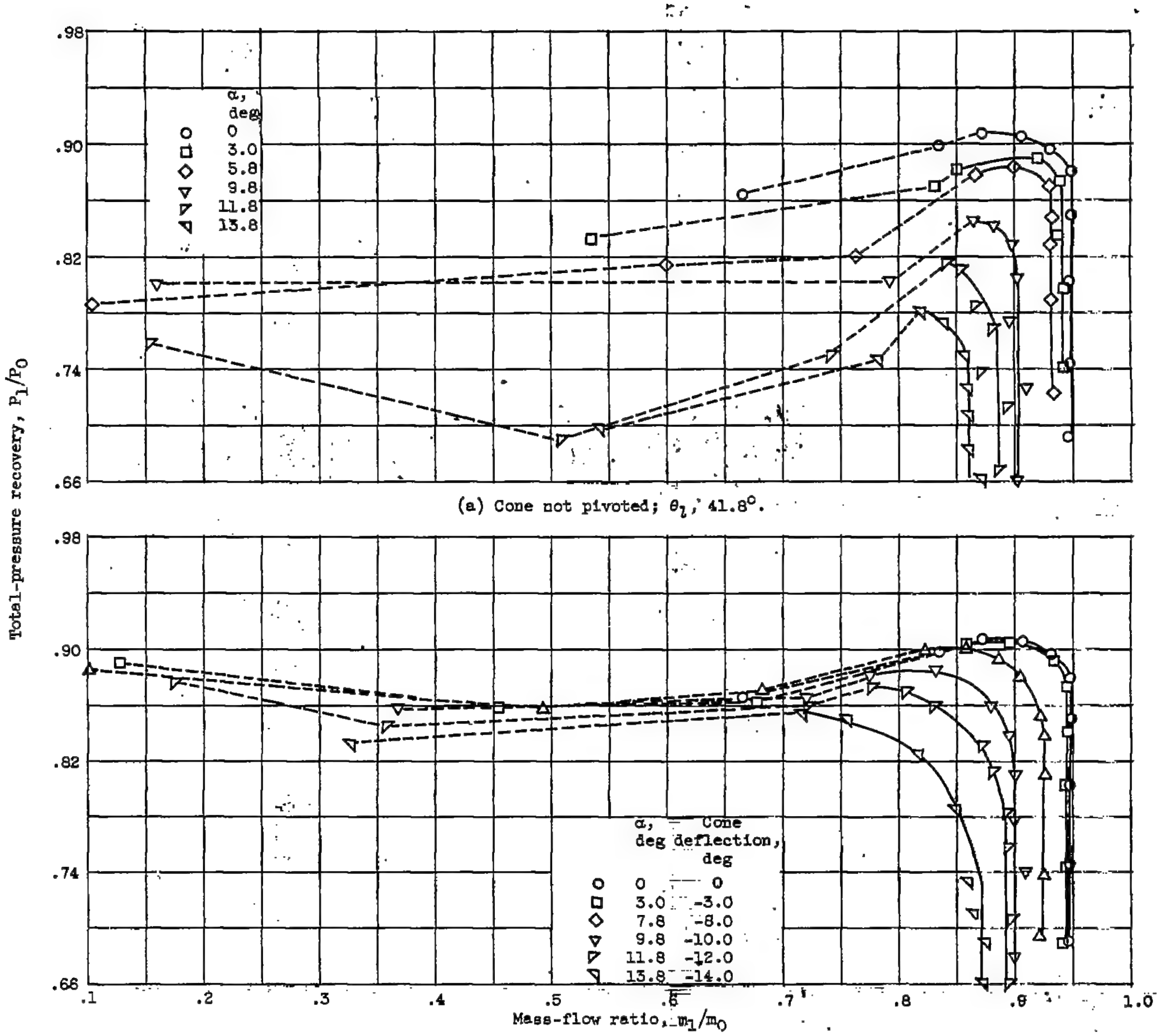

(a) Cone not pivoted; θ_l, 41.8°.

(b) Cone alined with free stream; θ_l, 41.8°.

Figure 5. - Effect of alining cone with free stream on diffuser performance at angle of attack.

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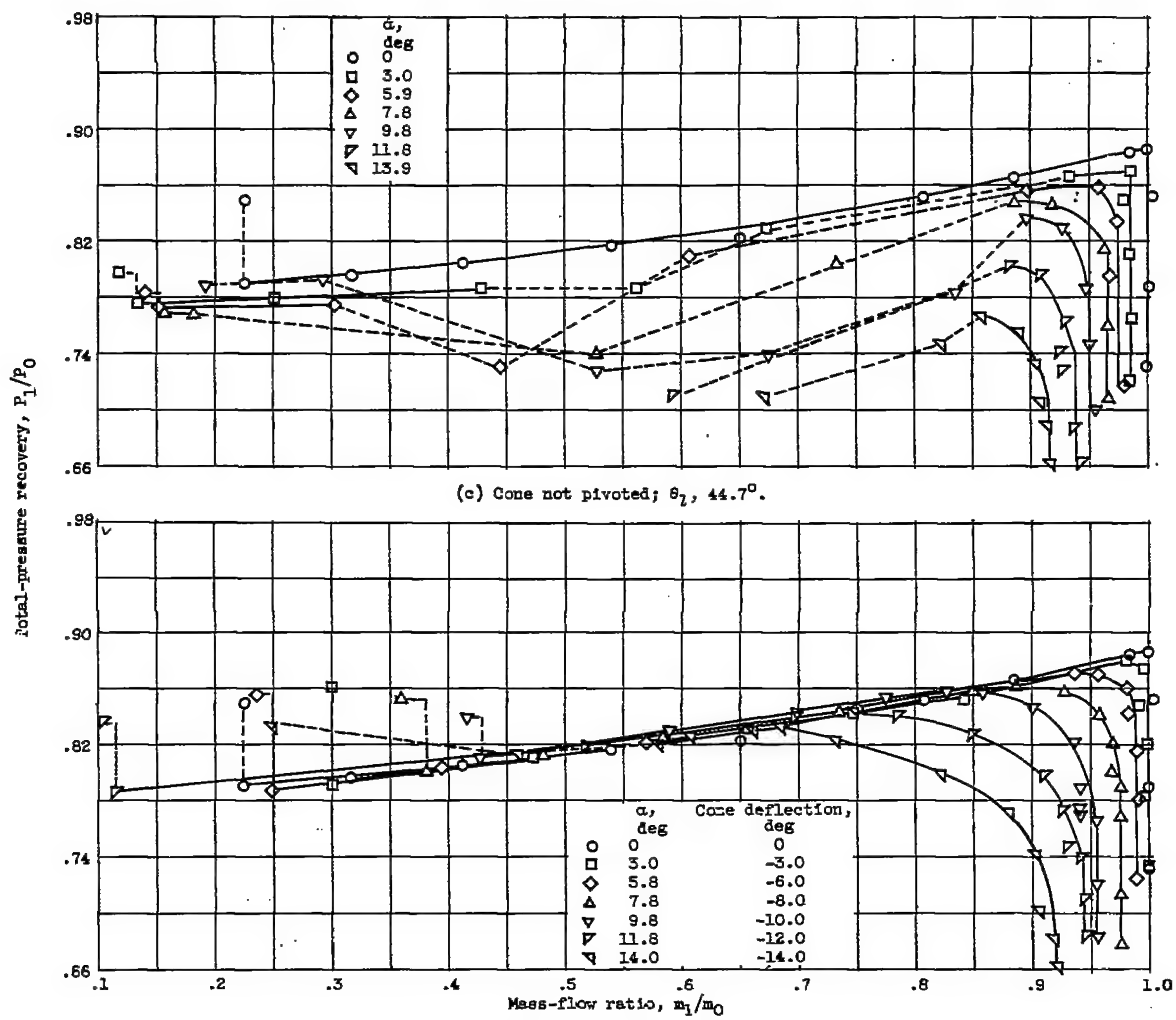
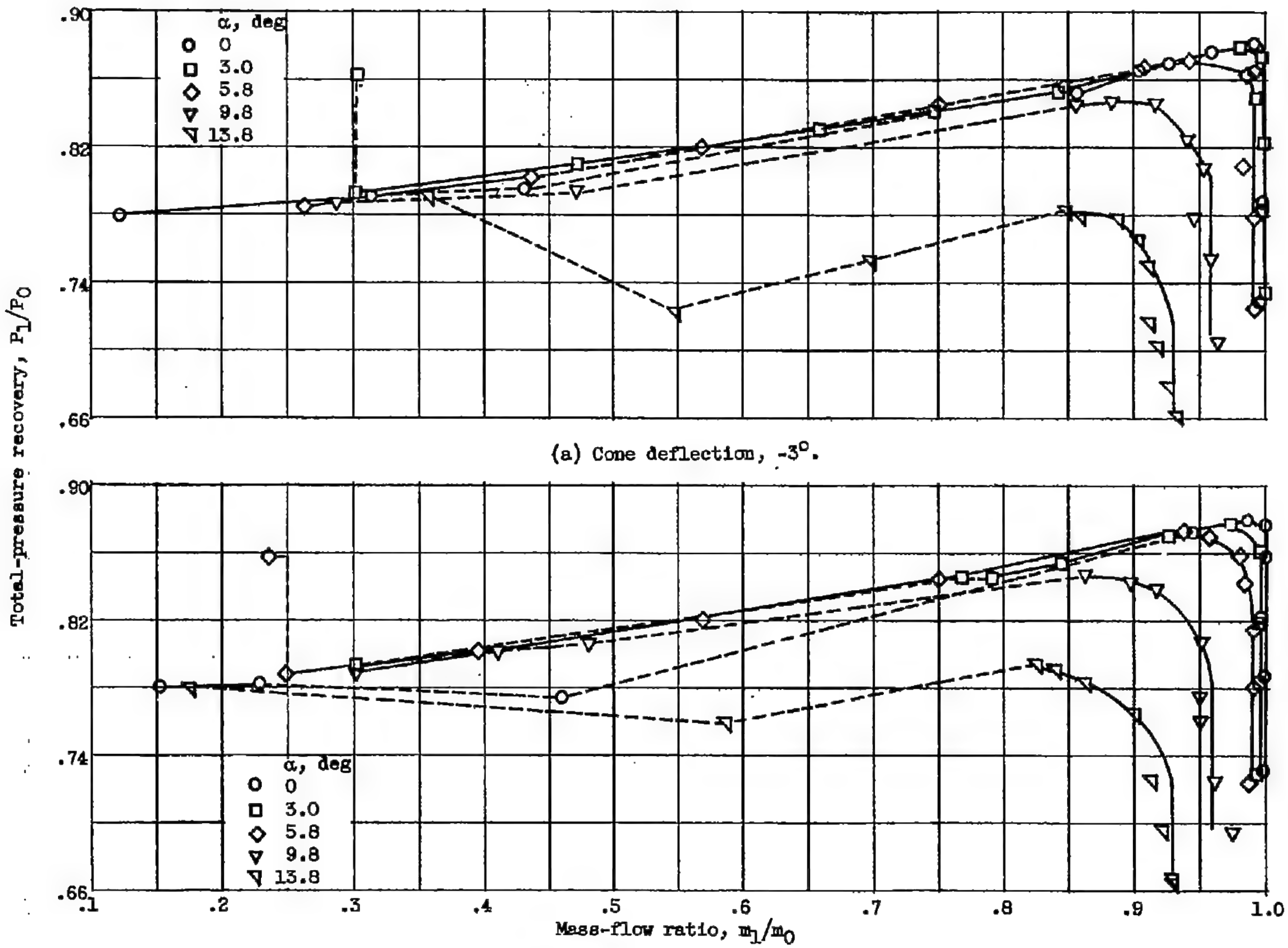


(c) Cone not pivoted; θ_l, 44.7°.

(d) Cone alined with free stream; θ_l, 44.7°.

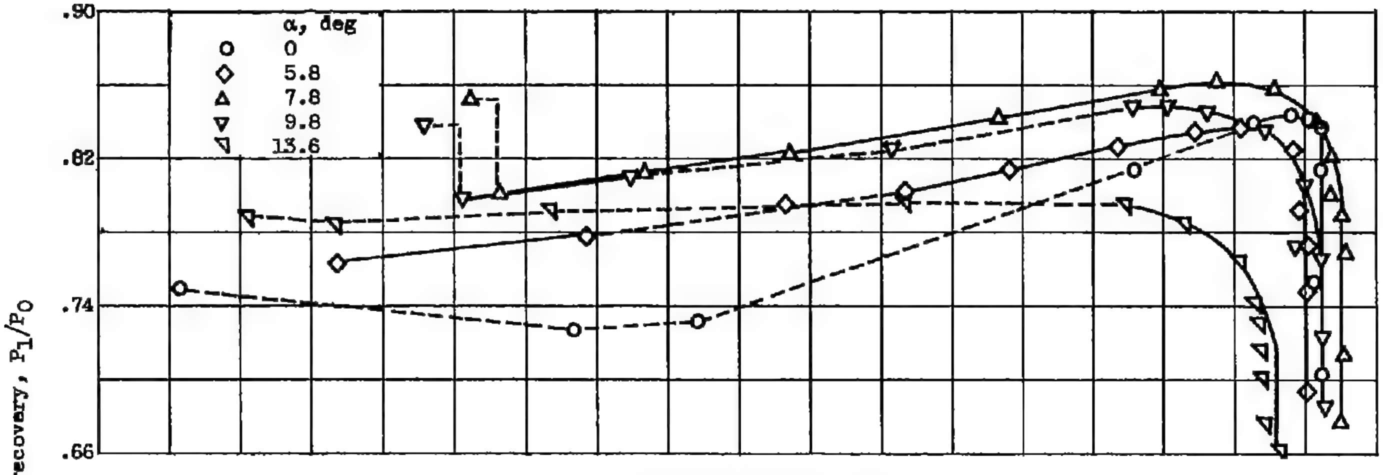
Figure 5. - Concluded. Effect of alining cone with free stream on diffuser performance at angle of attack.



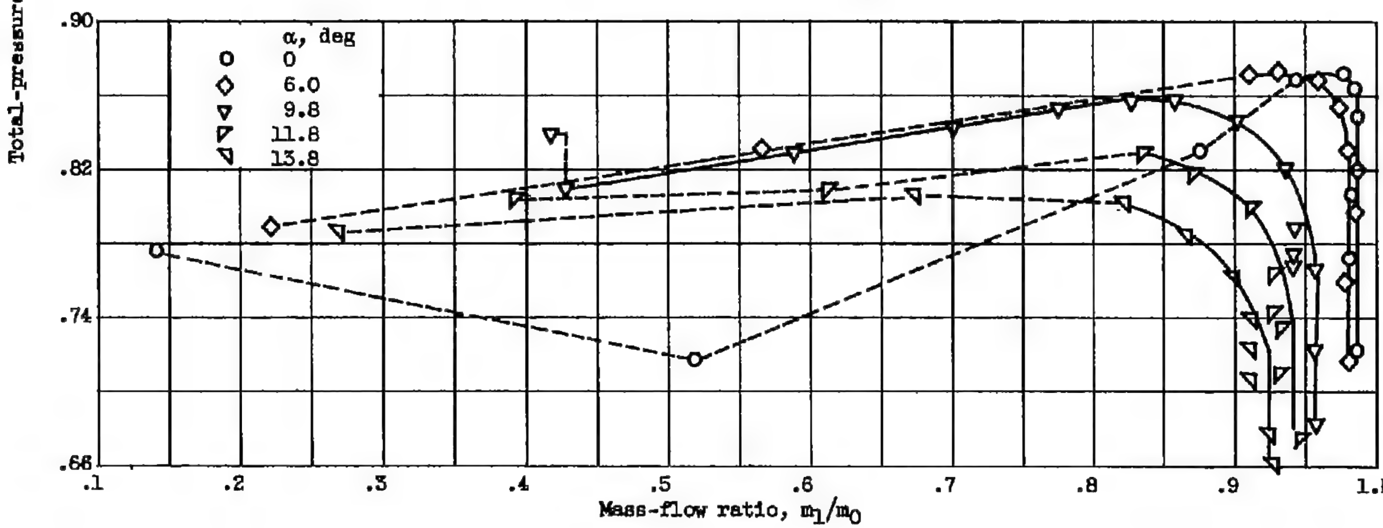
(a) Cone deflection, -3°.

(b) Cone deflection, -6°.

Figure 6. - Effect of pivoting cone to several angles with free stream on diffuser performance at angle of attack. θ_l, 44.7°.

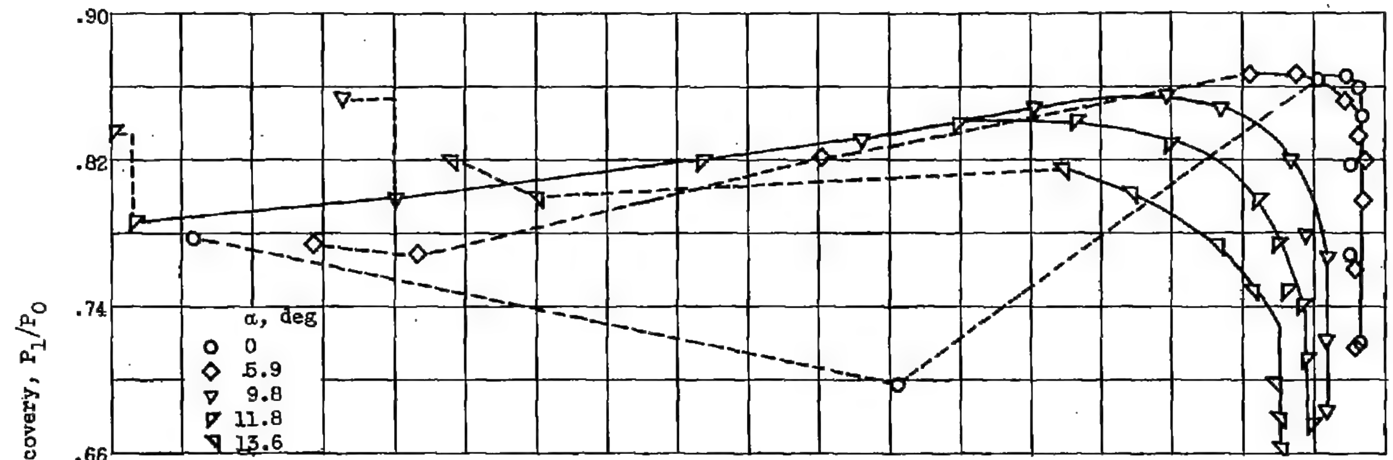


(c) Cone deflection, -8°.

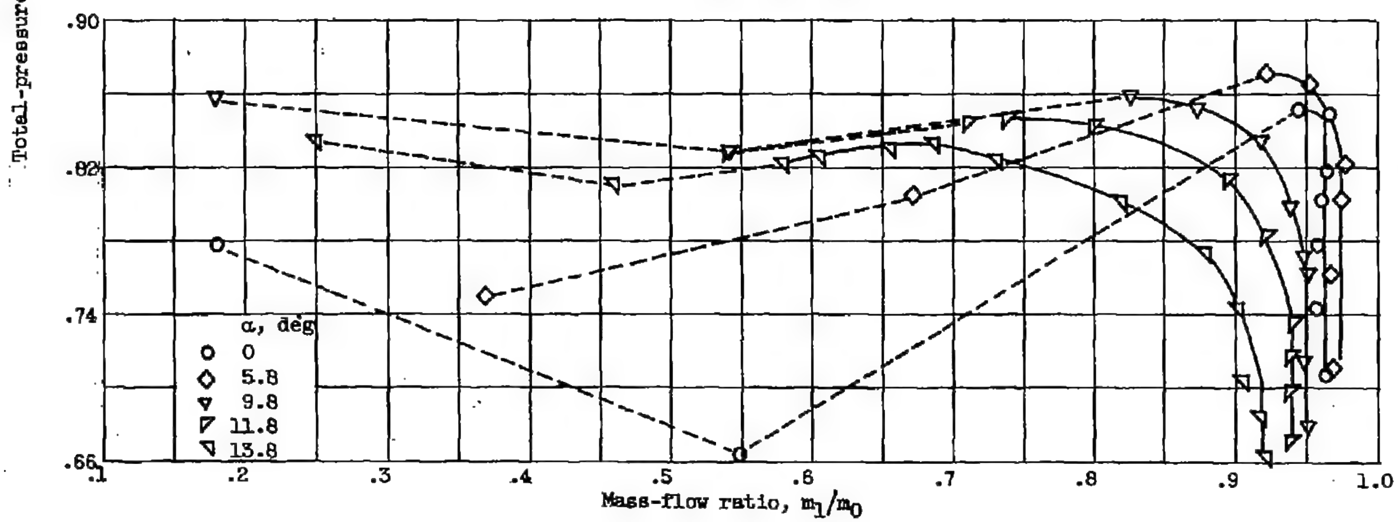


(d) Cone deflection, -10°.

Figure 6. - Continued. Effect of pivoting cone to several angles with free stream on diffuser performance at angle of attack. θ_l, 44.7°.



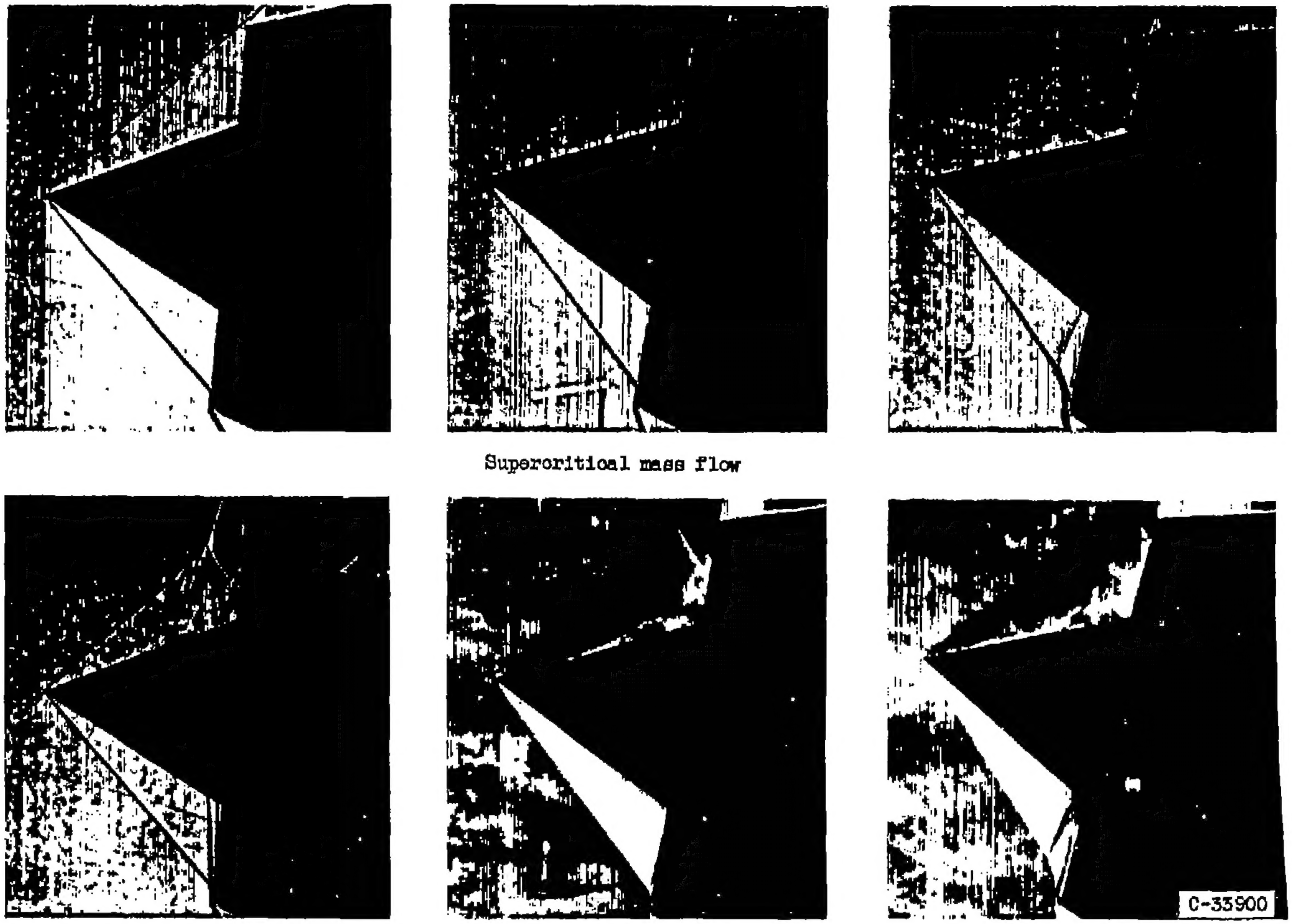
(e) Cone deflection, -12°.



(f) Cone deflection, -14°.

Figure 6. - Concluded. Effect of pivoting cone to several angles with free stream on diffuser performance at angle of attack. θ_l, 44.7°.

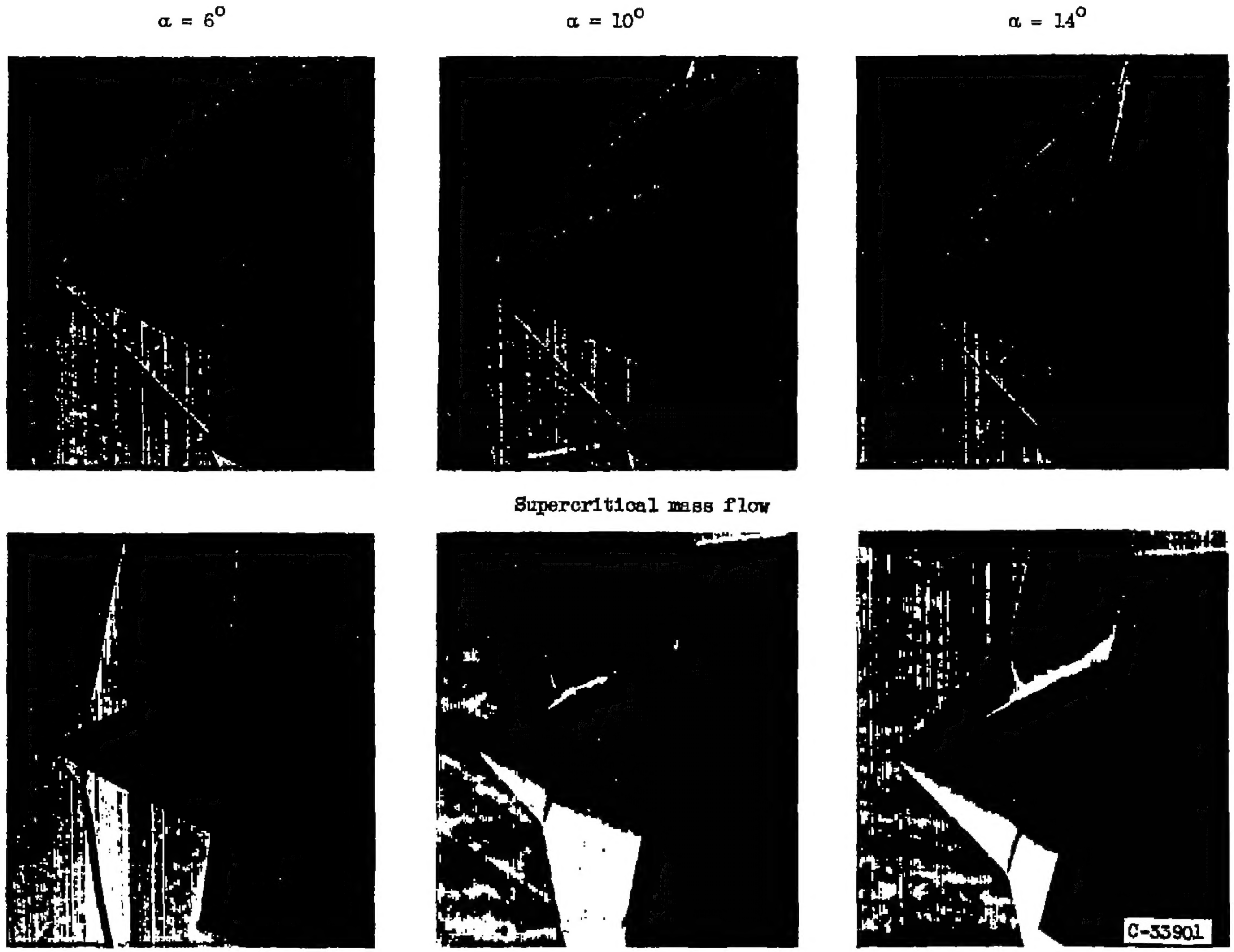
$\alpha = 6^{\circ}$ $\alpha = 10^{\circ}$ $\alpha = 14^{\circ}$



Supercritical mass flow

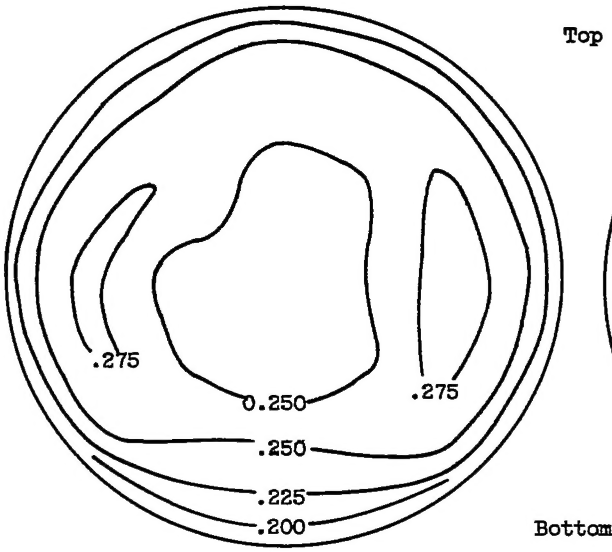
Minimum stable mass flow

Figure 7. - Shadowgraphs and schlieren photographs of inlet at angle of attack without pivoting cone. θ_l, 44.7°.

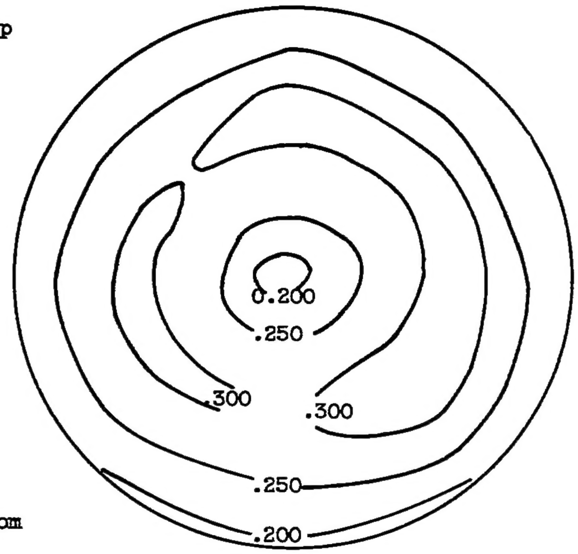


Minimum stable mass flow

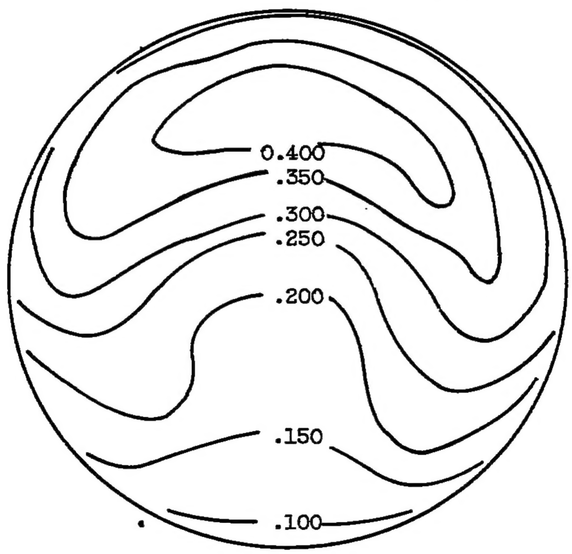
Figure 8. - Shadowgraph and schlieren photographs of inlet at angle of attack with cone alined with free stream. θ_l, 44.7°.



(a) θ_l, 41.8°; α, 0°; cone deflection, 0°; critical pressure recovery.

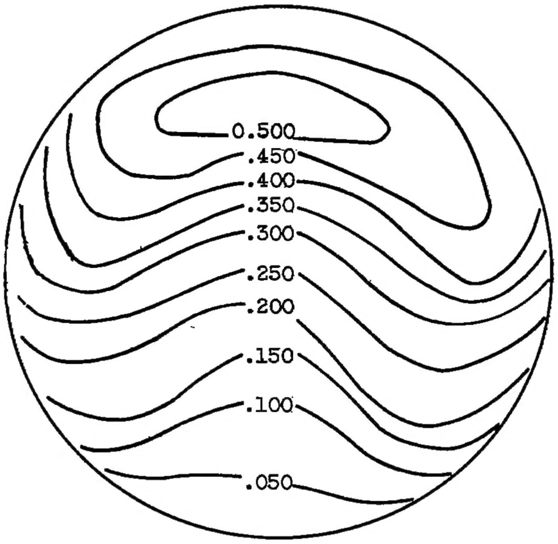


(b) θ_l, 44.7°; α, 0°; cone deflection, 0°; critical pressure recovery.

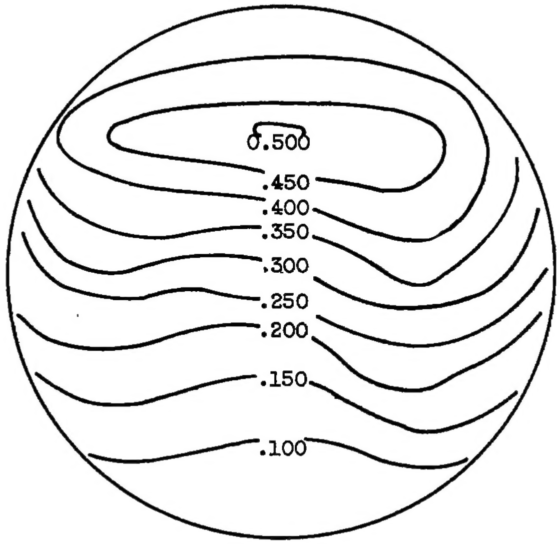


(c) θ_l, 44.7°; α, 6°; cone deflection, 6°; critical pressure recovery.

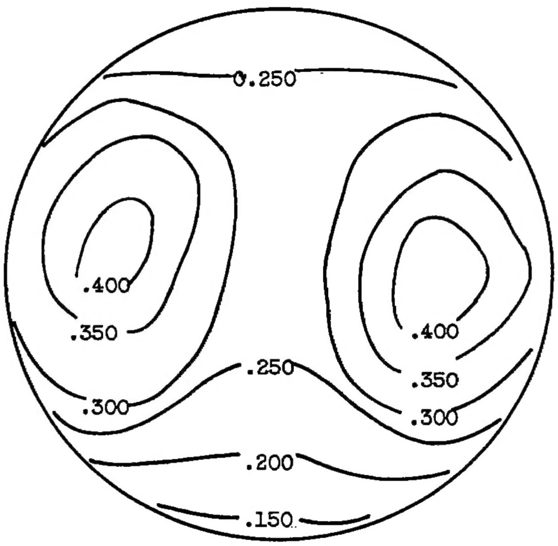
Figure 9. - Mach number contour maps at diffuser exit for differing operating conditions.



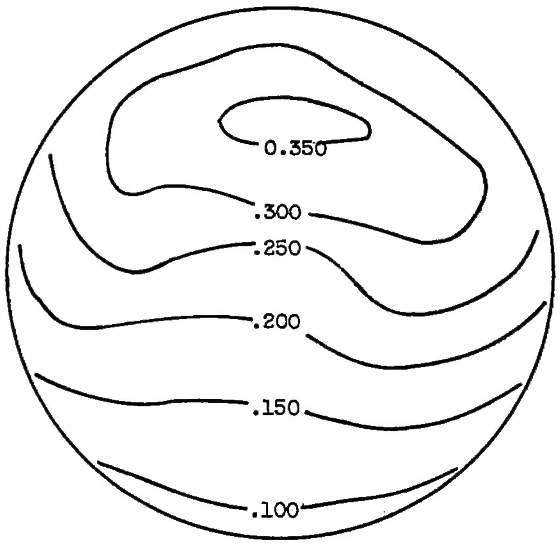
(d) θ_l, 44.7°; α, 10°; cone deflection, 10°; critical pressure recovery.



(e) θ_l, 44.7°; α, 10°; cone deflection, 0°; critical pressure recovery.



(f) θ_l, 44.7°; α, 10°; cone deflection, 10°; supercritical pressure recovery.



(g) θ_l, 44.7°; α, 10°; cone deflection, 10°; peak pressure recovery.

Figure 9. - Concluded. Mach number contour maps at diffuser exit for differing operating conditions.

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